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The Effect of Stress on Reliance Decisions

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Abstract

Appropriate reliance on automation is critical in high-risk/high-stress contexts such as military operations. The current study examines how stress affects the decision to rely on automation. Reliance will be examined using a decision making framework, taking into account the cognitive processes that are being affected by stress. Additionally, the role of feedback is essential in updating information to be able to make a more informed decision in the future. Reliability of automation will be manipulated so that actual reliability will be lower than expected reliability in one condition, and will be the same as expected in the other. Participants' ability to incorporate feedback into subsequent reliance decisions will be assessed between stress conditions. Finally, since motivation can encourage more deliberate thinking, motivation will be manipulated between subjects. A better understanding of how reliance decisions are made under stress can inform the design of systems for better human-automation collaboration.

1. Introduction

Human-automation teams have been seen to outperform both human-human teams and automation alone (e.g., Radiology [11], Freestyle Chess [22]). However, the potential of enhanced collaboration and performance will not be fully realized unless we understand how interacting with automation affects the thinking and decision making processes of humans, and how those cognitive processes translate into reliance behaviors.

Human collaboration with autonomy, from personal navigation assistance on a smart phone to global missile defense command and control systems, is only beneficial when the autonomous systems are relied on appropriately. Over- or under-reliance on automation can have serious consequences in high-risk contexts. Over reliance occurs when humans are too reliant on automation and fail to intervene when an error occurs, either due to overconfidence in the automation or not noticing the failure because they are "out-of-the-loop" [12]. For example, being so reliant on automated navigation that when an anomaly occurs (e.g., GPS signal is lost) it goes unnoticed and results in a ship running around [26]. Under reliance occurs when humans are reluctant to use automation, even when it out performs their own capabilities.

Because humans have limited processing capacity [21], most everyday judgments are based on heuristics and biases that give rise to an intuitive response [45]. The use of these mental shortcuts to inform judgments mostly leads to efficient decision making, however, intuitive judgment can also be misleading. Intuitive processes are in contrast to more deliberative processes that engage a slower, more methodical process [45]. While there are numerous factors involved in deciding whether to rely on automation (e.g., reliability, expertise, trust) [19], thinking through multiple dimensions requires engagement of deliberative thinking. The nature of the context and tasks will determine how much cognitive resources are required to think through these dimension. Some contexts or tasks may leave little cognitive resources, and therefore intuitive judgments are all that may be available. Understanding what these intuitive judgments look like in regards to reliance on automation needs to be better understood, particularly in high stress contexts.

Contexts characterized by high stress can alter thinking and decision making strategies, potentially causing humans to make inappropriate reliance decisions. There is evidence to suggest that pressure situations may lead to increased reliance [37]. Rice and Keller [37] examined reliance on automation with and without time pressure. They found time pressure increased overall reliance regardless of trust ratings. These findings suggest that time pressure induces rushed information processing leaving little time for deliberation, and consciously switching to an intuitive-based decision making approach may be the most optimal strategy. While time pressure might increase stress, it is not the same construct as stress. However,

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the study provides initial evidence to suggest reliance decisions are altered in pressured situations. Stress, in the absence of time pressure may lead to a similar, but unconscious shift in processing due to limited cognitive resources as opposed to a conscious shift in strategy due to time constraints.

While understanding when there is a change in reliance is important, it is more informative to know why there is a change in reliance. Looking at reliance in terms of thinking and decision making processes can help explain why a change in reliance occurs in high stress environments. Turning to the literature on stress and decision making helps to shed light on what might prompt this shift in reliance behavior.

2. Stress and decision making

The prefrontal cortex (PFC) is integral in higher order executive functions such as the integration of information and top-down attention allocation [7], [1]. In the context of optimal decision making, attending to and integrating relevant information is essential. Unfortunately, the PFC is largely negatively affected by the neurological reactions induced by stress [1].

Acute stress promotes the release of (a) glucocorticoids (cortisol in humans) through activation of the hypothalamic-pituitary-adrenal (HPA) axis [9], [16], [41], and (b) catecholamines (dopamine, epinephrine, and norepinephrine) through activation of the sympathetic-adrenal-medullary (SAM) axis [16], [38], [39]. Cortisol, dopamine, epinephrine, and norepinephrine can alter PFC and amygdala activity, leading to decreased activation in the PFC and increased activation in the amygdala [16]. The decline in resources needed to support PFC dependent functions can result in a shift towards a more intuitive, less deliberative processing of information [28]. Margittai et al. reported this shift in processing, in which participants who were administered hydrocortisone (cortisol agonist) scored lower on the cognitive reflection task (CRT; a task that measures deliberate over intuitive processing) [28].

As stated previously, engagement of PFC dependent functions is critical for deliberative decision making. In addition to deliberate processing, decision making requires enough cognitive resources to (a) retrieve relevant information (knowledge and past experiences) from long-term memory, (b) hold and integrate all information in working memory in order to make a decision, and (c) to use feedback to update existing information for subsequent decision making [5]. The reallocation of cognitive resources away from the PFC may lead to the inability to learn from, and integrate feedback that provides relevant information for subsequent decision making. In the context of reliance on automation, if expected reliability does not match actual reliability the cognitive resources need to be available to (a) notice such a discrepancy, and (b) incorporate feedback in order to appropriately update the new reliability information in memory. The use of feedback in decision making is important when previous outcomes provide information on which to base future decisions (e.g., the reliability of a decision aid). Unfortunately, research has shown that stress can impair the ability to learn from feedback [42]. This impairment to learn from feedback may result in a continued reliance on automation, even when the reliability of that automation is lower than expected.

The deleterious effect of stress on PFC-dependent functions causes a shift towards intuitive-based decision making, while the inability to learn from and integrate feedback can lead to suboptimal decisions when learning and deliberative processing are required. However, moderating factors, such as motivation, may ameliorate the deleterious effect of stress on decision making. Motivation has been shown to alter top-down attention allocation strategies [27]. Locke and Braver [27] found that monetary incentive (e.g., reward) was associated with changes in PFC activity. While motivation has been found to have a positive effect on PFC activity, it is unclear whether this effect extends to stress conditions.

3. Current study

At a general level, the current study aims to investigate the decision to rely on automation in contexts characterized by stress and uncertainty, particularly those related to military operations. More specifically, the goals of this study are to assess (a) if stress prompts an overall shift towards reliance on automation, (b) to what extent feedback is incorporated to inform subsequent decisions in stress and non-stress conditions, (c) the role of motivation as a potential moderator for the deleterious effect of stress on decision making, and (d) how strongly trust correlates with reliance between stress conditions.

Participants will be recruited from The Naval Postgraduate School. Participation will not be limited to students, but is expected to be approximately 85% students, based on previous experimentation. While the age is only restricted to above 18 years old, the mean age, based on previous studies is expected to be 35-40. However, there are more students in their early 20s, and therefore the mean age may be lower than anticipated. Additionally, it is expected that the majority of participants will be male, previous studies have seen anywhere from 59% to 85% male dominant. While the results of this study will be generalizable to military officers (all branches are represented at the school), if enough civilians are recruited, differences between populations will be examined.

Participants will be exposed to either a stress or control condition, after which they will complete a pattern learning task that involves choosing what number (i.e., 1, 2, or 3) will come next in the sequence. Participants will initially make their decision, they will then receive advice from a decision aid, and then they will make their final choice. . The decision to rely on automation is only relevant when there is a discrepancy in the participant's choice and the decision aid's advice; in such cases the participant will then need to decide whether to rely on the decision aid or stay with their own choice [10]. Reliability of the decision aid will be manipulated to assess whether feedback is incorporated into subsequent reliance decisions between the stress conditions.

Based on the literature covered previously, the following hypotheses are predicted:

1. The deleterious effect of stress on cognitive functions, specifically working memory and attention are hypothesized to result in an automatic, intuitive-based decision making approach, and an overall increase in reliance on automation in the stress than non-stress condition.
2. Feedback about the reliability of the decision aid that is inconsistent with the expected reliability of the aid will be noticed and incorporated into subsequent reliability decisions less frequently in the high than low stress condition.
3. Motivation will have a moderating effect on the ability to notice and incorporate feedback information via enhanced attention to relevant goal-oriented information in both the stress and non-stress conditions.
4. While reliance is predicted to increase in the stress compared to non-stress condition, no difference is predicted in trust behavior (as assessed by a subjective questionnaire, and trust game [3]).

4. Procedure and materials

4.1. Stress manipulation

Stress induction in a laboratory setting can be challenging, particularly in obtaining physiological responses that are congruent with real world stressors. In a meta-analysis [9], laboratory stress induction techniques that were uncontrollable (i.e., inability to control one or more aspects of the situation) and included social-evaluative threat (i.e., disapproval of others) produced the highest elevations in the stress-related hormone, cortisol. The most commonly used stress-induction technique is the Trier Social Stress Test (TSST; [23]), and includes both uncontrollability and social-evaluative threat. The TSST is currently considered the "gold standard" to elicit stress responses in a laboratory setting [41].

Participants will be randomly assigned to the high or low stress condition. In the high stress condition, The TSST will be administered, and consists of three five-minute phases: (a) anticipatory phase – participants will be told to prepare a speech explaining why they should receive their next promotion; (b) speech phase – participants will deliver their speech in front of a "committee" of two people that they are told are experts in non-verbal behavior; and (c) mental math phase – participants will be asked to continually subtract the number 13 from 1022 as fast and accurately as possible. In the low stress condition, a TSST control procedure will be administered (p-TSST [17]), which consists of the same phases as the TSST, but lacks the social-evaluative and uncontrollability elements that are considered the main stressors underlying the effectiveness of the TSST [9].

Stress will be assessed through (a) physiological indicators, (b) salivary cortisol, and (c) a subjective questionnaire to ensure participants responded as intended to the stress manipulation.

a. The physiological indicators of stress, heart rate variability (HRV) and electrodermal activity (EDA), will be obtained through the Empatica E4 wristband [15]. These measures will be taken continuously throughout the experiment. While there are several indices that can be taken as measures of HRV, the four most common indices will be used in this study; (a) standard deviation of the intervals (SDNN) [30]; (b) square root of the mean squared differences between inter-beat intervals (RMSSD) [32]; (c) the proportion of the inter-beat interval (RR) that deviate by more than 50ms from the previous interval (pNN50) [43], and (d) the low to high frequency ratio (LF/HF Ratio) [24], [43].

b. Salivary cortisol is commonly collected as indication of stress in laboratory studies, as cortisol is known to be released in response to a stressor [41]. Salivary cortisol will be collected six times throughout the experiment (after the rest period, 1 minute prior to the stress induction, 1 minute after stress induction, and every 10 minutes afterwards [23] via passive drool, and stored at -20 degrees Celsius [41]. Due to concerns in awakening cortisol levels, all testing will take place in the afternoon, starting at 1300 [41]. Saliva samples containing visible blood will be discarded. Cortisol is sensitive to various factors including health, medication use, and food intake. Therefore, participants will be asked to abstain from exercise, smoking, eating, or drinking for an hour before the experiment. There are also exclusionary criteria for participation. Participants will be excluded if they have a psychiatric illness, cardiovascular disease, or neuroendocrine disorder. Additional factors that affect cortisol will be accounted for in the exit questionnaire, such as caffeine and food intake, smoking, any medications currently being taken, menstrual cycle – for females, and what time they woke up that morning [41].

Repeated sampling allows for cortisol change comparison in response to the stressor ([41]). To test whether there was a difference in cortisol between the stress and no stress conditions a 2 (stress condition) x 6 (time points) repeated measures ANOVA will be run, Greenhouse-Geisser correction will be applied as appropriate (e.g., [34]; [28]; [42]; [13]). Additionally, because the interest is specifically in the increase in cortisol over time, area under the curve with respect to increase (AUC_I) will be assessed between groups as well ([36], [29], [25]).

Regardless of assigned condition, it is also interesting to see if cortisol increase as determined by AUC_I predicts reliance on automation. In a hierarchical regression analysis, with reliance as the dependent variable, AUC_I will be entered as the first independent variable, followed by Ospan score, and finally, an interaction variable AUC_I and Ospan.

c. The Positive and Negative Affect Schedule (PANAS [48]) will be administered twice (at baseline and again after the TSST). The PANAS measures affect on a 5-point scale, and consists of 10 positive and 10 negative emotions.

4.2. Experimental task

The main task participants will engage in has been repeatedly used in reliance on automation studies (e.g., [10]). Participants are told to make a prediction about the next number in a pattern learning task (either 1, 2, or 3). The pattern learning task requires gradual learning, so that in the first few trials when participants are presented with 1, 2, or 3, they will have to guess. After a few repeated trials, they should start to see a pattern forming, and be able to make a more informed prediction. The sequence of each trial is as follows: (a) participants will make their prediction, (b) the decision aid will offer a suggestion, (c) participants will make their final prediction, (d) participants will rate their confidence in their final prediction, and (e) the correct answer will be shown. There will be one practice round consisting of 40 trials, and then one experimental block consisting of 100 trials. The pattern that will be used is 2, 3, 1, 2, 3 [10]. The pattern is generated so that there are 100 numbers. There will be deviations in the pattern to prevent perfect learning; there has to be some ambiguity in order to decide whether or not to rely on automation when there is disagreement.

4.3. Automation reliability

There will be two decision aids with different reliabilities. Decision Aid 1 will have 85% reliability, and decision Aid 2 will have 60% reliability. Participants will be told in the beginning that both decision aids have a reliability of approximately 85%. Therefore, an 85% reliable decision aid would match participants' expectations of high reliability, however, 60% would not match expectations, and is generally considered unreliable (i.e., < 70% [49]). Only one decision aid will offer advice per trial, however the decision aids will be presented evenly via, intermixed blocks of 10, so that the participants are utilizing the same decision aid for 10 iterations at a time. The presentation order will be counterbalanced between participants. The practice trials will be presented with 85% reliability, consistent with expectation.

4.4. Motivation

Participants will be randomly assigned to the motivation or non-motivation condition. Participants in the motivation condition will earn $0.20 for each correct response, with the potential to earn $30 over all the experimental trials. Participants in the non-motivation condition will earn money for correct responses, however, they will not be told beforehand, nor will they be shown an ongoing total. A reward, as opposed to loss, paradigm was chosen due the evidence showing that loss may induce worry and task irrelevant thoughts, and may not necessarily lead to increased performance [35]. Paschke et al. [35] found that although losses increased general attention control, and gains increased specific attention control, performance was better in the gain than loss condition. Therefore, this study will utilize gains instead of losses (a) in order to maximize performance, and (b) to avoid confounding the effect of stress with additional stress caused by potential loss [18].

4.5. Procedure

After signing the informed consent, an Empatica E4 wristband will be fitted on the participant's wrist to start collecting physiological data. Participants will then rest for 10 minutes to collect baseline physiological readings. After rest, a saliva sample will be collected and participants will fill out the PANAS. A measure of working memory capacity, the operation span task (OSPAN; [44]) will be completed after the

PANAS. Next, participants will be introduced to the experimental task with a cover story; a modified version of the story used in [10] where participants will be told that a software company is interested in evaluating their "pattern learning software before applying it to more complex tasks on naval ships" [10, p. 416]. The cover story will lead to task instructions, and then participants will practice the experimental task. Instructions and practice will be conducted before the stress manipulation so that task learning is not impaired by stress. The TSST or p-TSST task will be administered, after which another PANAS will be administered. Participants will then complete the CRT before performing the experimental task. Afterwards, the participant will be administered a series of measures and questionnaires in the following sequence, (a) trust game, (b) lottery game, and (c) exit questionnaire. Finally, participants will be fully debriefed, asked for a second consent to use their data, and paid according to how much they earned in the experiment, with a ceiling of $50. Incentive-based compensation is commonly used in motivation or trust designs (e.g., [47], [4], [8], [20]).

4.6. Eye tracking

Eye tracking is a common measure to infer cognitive processes [31]. In decision making research, dwell time and pupil dilation have been used to understand the cognitive processes involved in decisions [6]. Participants will be calibrated to a non-invasive, screen-based eye tracker that samples at 60Hz and measures pupilometry. Calibration will occur after participants complete the first PANAS, but before the Ospan task. Pupil dilation in the Ospan task will be used as an indication of cognitive load. Participants will be recalibrated after the TSST (or pTSST). Eye tracking and pupil dilation measures will then be collected throughout the remainder of the experiment, with particular interest in the experimental task, trust games, CRT, and lottery game.

4.7. Operation span task (OSPAN)

Working memory capacity has been shown to moderate the effect of stress on some PFC-dependent tasks (e.g., model-based learning; [33]). Because of this, it is important to get a pre-stress measure of working memory capacity to assess if individual differences in working memory moderate the effect of stress on decision making. The automated OSPAN task procedure will be used [46], where a mathematical equation is shown and participants have to indicate whether it is correct, then a letter is presented on the screen. After a set of 3-7 trials is shown, participants then have to recall the letters that were presented in the correct order of presentation. There will be a total of 75 trials so that all set lengths (3-7) are presented three times.

4.8. Trust game

The trust game is a common measure of human-human trust, originally developed in economic literature [3]. The trust game is usually played between two people, where one person will invest a certain amount of money (investor) with the other person (investee), however much is invested is tripled and given to the investee. The investee then decides how much of the money to keep and how much to share back with the investor. In the current experiment, the investee will be the decision aid. The participant will be given the opportunity to invest up to half of the money they earned throughout the experiment with the decision aids they were working with; they can invest with either one or both. They will be told that the money they decide to invest will be tripled, and that the decision aid will then make the decision on how much to return to the participant, the decision aid can return any amount of the money received. For example, if the participant invested $10 with the decision aid, the decision aid would receive $30, and could hypothetically share $0 to $30 back with the participant. The trust game will be administered to examine (a) if reliance on automation correlates with trust game investments, and (b) subjective trust measurement correlates with a commonly used objective trust measure. Participants will find out at the end of the experiment how much the decision aid chose to share back with them. Again, the ceiling for earnings is $50.

4.9. Cognitive reflection task (CRT)

The CRT is a measure of analytic thinking [14]. The CRT is a short task, involving three questions.

1. *A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?*
2. *If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets?*
3. *In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover the half of the lake?*

Stress has been found to have a negative impact on analytic thinking, resulting in lower CRT scores [28], [40]. Therefore, the CRT will be used as an objective measure of analytic thinking under stress.

4.10. Lottery game

Because some investments might be seen as a measure of propensity for risk as opposed to an indication of trust, it is important to have a risk task. The lottery task is set-up the same as the trust game, except participants will gamble (instead of invest) up to half of their earnings and will be told there will be a random chance that they will receive any money back [2].

4.11. Exit questionnaire

The exit questionnaire will be administered last, and will (a) assess reliability and trust, (b) account for potential confounds that would alter cortisol levels, and (c) collect demographic data.

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